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Steel Frame Design Manual

API RP 2A-WSD 22nd

API RP 2A-WSD 22nd Steel Frame Design Manual

for

SAP2000®

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Contents

1 Introduction

This manual describes the steel frame design algorithms in the software for API Recommended Practice 2A-WSD 22nd Edition (American Petroleum Institute, 2014). The design algorithms in the software for API RP 2A-WSD 22nd cover allowable stress checks for typical structural elements used in offshore steel structures, as detailed in this manual. Such elements are tubular members and tubular joints. For other types of structural elements, the software uses AISC ASD 9th Edition. Requirements of the code not documented in this manual should be considered using other methods.

This manual documents the design details for cylindrical sections having thickness $t \geq 6$mm, $D/t < 300$. Members of other section shapes are designed in accordance with AISC ASD 9th Edition (American Institute of Steel Construction, 1989).

It is important to read this entire manual before using the design algorithms to become familiar with any limitations of the algorithms or assumptions that have been made.

1.1 Units

The API RP 2A-WSD design code is based on metric and imperial units. This manual is written using imperial units, unless noted otherwise. Any units, imperial, metric, or MKS may be used in the software in conjunction with API RP 2A-WSD design.

1.2 Axes Notation

The software analysis results refer to the member local axes system, which consists of the 2-2 axis and the 3-3 axis. The API RP 2A-WSD design code refers to x-x and y-y axes, which are equivalent to the software 3-3 and 2-2 axes, respectively. These notations may be used interchangeably in the design algorithms, although every effort has been made to use the design code convention where possible.

1.3 Symbols

The following table provides a list of the symbols used in this manual, along with a short description. Where possible, the same symbol from the design code is used in this manual.

A	Cross sectional area, in^2
C	Critical elastic buckling coefficient
C_h	Critical hoop buckling coefficient
C_m	Reduction factor
D	Outside diameter, in
E	Young's modulus of elasticity, ksi
f_a	Design tensile stress, ksi
F_a	Allowable compressive stress, ksi
f_b	Design bending stress, ksi
F_b	Allowable bending stress, ksi
F_e'	Euler stress, ksi
f_h	Hoop stress due to hydrostatic pressure, ksi
F_{hc}	Critical hoop buckling stress, ksi
F_{he}	Elastic hoop buckling stress, ksi
F_t	Allowable tensile stress, ksi
f_v	Design beam shear stress, ksi
F_v	Allowable beam shear stress, ksi
f_{vt}	Design torsional shear stress, ksi
F_{vt}	Allowable torsional shear stress, ksi
f_x	Design compressive stress, ksi
F_{xc}	Inelastic local buckling stress, ksi
F_{xe}	Elastic local buckling stress, ksi
F_y	Yield strength, ksi
g	Gap distance, in
I_p	Polar moment of inertia, in^4
K	Effective length factor
l	Unbraced length, in
L	Length between stiffening rings, diaphragms, or end connections, in
M	Bending moment, kip-in
M	Geometric parameter
M_a	Allowable brace bending moment, kip-in
M_t	Torsional moment, kip-in
p	Hydrostatic pressure, ksi

P	Axial force, kip
P_a	Allowable brace axial load, kip
Q_f	Chord load factor
Q_g	Gap factor
Q_u	Ultimate strength factor
Q_β	Geometric factor
r	Radius of gyration, in
SF_b	Safety factor for bending
SF_h	Safety factor against hydrostatic collapse
SF_x	Safety factor for axial force
t	Wall thickness, in
V	Transverse shear force, kip
ν	Poisson's ratio
θ	Angle between the chord and the brace

2 Member Design

This chapter provides the details of the structural steel design and stress check algorithms that are used for cylindrical member design and checking at each output station in accordance with API RP 2A-WSD.

Cylindrical members subjected solely to axial tension, axial compression, bending, shear, or hydrostatic pressure are designed in accordance with API RP 2A-WSD Sections 6.2.1 to 6.2.5, respectively. Cylindrical members subjected to combined loads without hydrostatic pressure are designed in accordance with API RP 2A-WSD Sections 6.3.2 and 6.3.3. Cylindrical members subjected to combined loads with hydrostatic pressure are designed in accordance with API RP 2A-WSD Sections 6.3.4 and 6.3.5.

2.1 Safety Factors

The safety factors used in calculating allowable stresses in the following sections are defined as:

Table 1 - Safety factors

	Loading			
Design Condition	**Axial Tension**	**Axial Compression**	**Bending**	**Hoop Compression**
Basic allowable stresses	1.67	2.0	F_y/F_b	2.0
One-third increase in allowable stresses is permitted	1.25	1.5	$F_y/(1.33F_b)$	1.5

2.2 Tension Check

Members subjected to axial tension are checked for the following condition:

$$\frac{f_a}{F_t} \leq 1.0 \qquad \text{[API 6.2.1]}$$

The allowable tensile stress, F_t, is defined as:

$$F_t = 0.6F_y \qquad \text{[API Eq. 6.1]}$$

2.3 Compression Check

Members subjected to axial compression are checked for the following condition:

$$\frac{f_a}{F_a} \leq 1.0 \qquad \text{[API 6.2.2]}$$

The allowable compressive stress, F_a, is defined as:

$$F_a = \begin{cases} \dfrac{\left[1 - \dfrac{(Kl/r)^2}{2C_c^2}\right] F_y}{5/3 + \dfrac{3(Kl/r)}{8C_c} - \dfrac{(Kl/r)^3}{8C_c^3}} & \text{for} \quad Kl/r < C_c \\ \dfrac{12\pi^2 E}{23(Kl/r)^2} & \text{for} \quad Kl/r \geq C_c \end{cases} \qquad \text{[API Eq. 6.2 \& Eq. 6.3]}$$

where,

$$C_c = \left[\frac{2\pi^2 E}{F_y}\right]^{0.5}$$

$$F_y = \begin{cases} F_y & \text{for} \quad D/t \leq 60 \\ \min(F_{xe}, F_{xc}) & \text{for} \quad D/t > 60 \end{cases}$$

For members with $D/t > 60$, the yield strength, F_y, in the above equations is replaced by the critical local buckling stress, defined as the minimum of F_{xe} or F_{xc}.

The elastic local buckling stress, F_{xe}, is defined as:

$$F_{xe} = 2CE\, t/D \qquad \text{[API Eq. 6.4]}$$

where the critical elastic buckling coefficient, $C = 0.3$.

The inelastic local buckling stress, F_{xc}, is defined as:

$$F_{xc} = F_y\left[1.64 - 0.23(D/t)^{1/4}\right] \leq F_{xe} \qquad \text{[API Eq. 6.5]}$$

2.4 Flexure Check

Members subjected to bending are checked for the following condition:

$$\frac{f_b}{F_b} \leq 1.0 \qquad \text{[API 6.2.3]}$$

The allowable bending stress, F_b, is defined as:

$$F_b = \begin{cases} 0.75F_y & \text{for} \quad \frac{D}{t} \le \frac{1500}{F_y} \\ \left[0.84 - 1.74\frac{F_y D}{Et}\right]F_y & \text{for} \quad \frac{1500}{F_y} < \frac{D}{t} \le \frac{3000}{F_y} \\ \left[0.72 - 0.58\frac{F_y D}{Et}\right]F_y & \text{for} \quad \frac{3000}{F_y} < \frac{D}{t} \le 300 \end{cases}$$ [API Eq. 6.6, 6.7, and 6.8]

2.5 Shear Check

Members subjected to beam shear are checked for the following condition:

$$\frac{f_v}{F_v} \le 1.0$$ [API 6.2.4.1]

The maximum beam shear stress, f_v, and the allowable beam shear stress F_v are defined as:

$$f_v = \frac{V}{0.5A}$$ [API Eq. 6.9]

$$F_v = 0.4F_y$$ [API Eq. 6.10]

Members subjected to torsional shear are checked for the following condition:

$$\frac{f_{vt}}{F_{vt}} \le 1.0$$ [API 6.2.4.2]

The maximum torsional shear stress, f_{vt}, and the allowable torsional shear stress F_{vt} are defined as:

$$f_{vt} = \frac{M_t(D/2)}{I_p}$$ [API Eq. 6.11]

$$F_{vt} = 0.4F_y$$ [API Eq. 6.12]

2.6 Hoop Buckling Check

Members subjected to external pressure are checked for the following condition:

$$f_h \le F_{hc}/SF_h$$ [API Eq. 6.13]

The hoop stress due to hydrostatic pressure, f_h, is defined as:

$$f_h = pD/2t$$ [API Eq. 6.14]

The critical hoop buckling stress, F_{hc}, is defined as:

$$F_{hc} = \begin{cases} F_{he} & \text{for} \quad F_{he} \le 0.55F_y \\ 0.45F_y + 0.18F_{he} & \text{for} \quad 0.55F_y < F_{he} \le 1.6F_y \\ \dfrac{1.31F_y}{1.15 + \left(F_y/F_{he}\right)} & \text{for} \quad 1.6F_y < F_{he} \le 6.2F_y \\ F_y & \text{for} \quad F_{he} > 6.2F_y \end{cases}$$ [API Eq. 6.18]

The elastic hoop buckling stress, F_{he}, is defined as:

$$F_{he} = 2C_h E\, t/D$$ [API Eq. 6.16]

The critical hoop buckling coefficient, C_h, is defined as:

$$C_h = \begin{cases} 0.44\, t/D & \text{for} \quad M \ge 1.6\, D/t \\ 0.44(t/D) + \dfrac{0.21(D/t)^3}{M^4} & \text{for} \quad 0.825\, D/t \le M < 1.6\, D/t \\ 0.736/(M - 0.636) & \text{for} \quad 3.5 \le \mathrm{M} < 0.825\, D/t \\ 0.755/(M - 0.559) & \text{for} \quad 1.5 \le M < 3.5 \\ 0.8 & \text{for} \quad M < 1.5 \end{cases}$$

The geometric parameter, M, is defined as:

$$M = \frac{L}{D}(2\, D/t)^{0.5}$$ [API Eq. 6.17]

2.7 Axial Tension and Bending Check

Members subjected to combined axial tension and bending loads, without hydrostatic pressure, are checked for the following condition:

$$\frac{f_a}{0.6F_y} + \frac{\sqrt{f_{bx}^2 + f_{by}^2}}{F_b} \le 1.0$$ [API Eq. 6.21]

Members subjected to combined axial tension, bending, and hydrostatic pressure are checked for the following condition:

$$A^2 + B^2 + 2\nu|A|B \le 1.0$$ [API Eq. 6.26]

where,

$$A = \frac{f_a + f_b - (0.5f_h)}{F_y}(SF_x)$$

$$B = \frac{f_h}{F_{hc}}(SF_h)$$

2.8 Axial Compression and Bending Check

Members subjected to combined axial compression and bending, without hydrostatic pressure, are checked for the following conditions:

$$\frac{f_a}{F_a} + \frac{\sqrt{\left[\frac{C_{mx} f_{bx}}{1 - \frac{f_a}{F'_{ex}}}\right]^2 + \left[\frac{C_{my} f_{by}}{1 - \frac{f_a}{F'_{ey}}}\right]^2}}{F_b} \leq 1.0$$ [API Eq. 6.23]

$$\frac{f_a}{0.6F_y} + \frac{\sqrt{f_{bx}^2 + f_{by}^2}}{F_b} \leq 1.0$$ [API Eq. 6.21]

where,

$$F'_e = \frac{12\pi^2 E}{23(Kl/r)^2}$$ [AISC H1]

The reduction factors, C_{mx} and C_{my} are calculated according to AISC H1.

If $\frac{f_a}{F_a} \leq 0.15$, the previous two conditions are substituted by the following condition:

$$\frac{f_a}{F_a} + \frac{\sqrt{f_{bx}^2 + f_{by}^2}}{F_b} \leq 1.0$$ [API Eq. 6.22]

Members subjected to combined axial compression, bending, and hydrostatic pressure are checked for the following conditions:

$$\frac{f_a + (0.5f_h)}{F_{xc}}(SF_x) + \frac{f_b}{F_y}(SF_b) \leq 1.0$$ [API Eq. 6.27]

$$SF_h \frac{f_h}{F_{hc}} \leq 1.0$$ [API Eq. 6.28]

If $f_x > 0.5F_{ha}$, the following condition is also satisfied:

$$\frac{f_x - 0.5F_{ha}}{F_{aa} - 0.5F_{ha}} + \left(\frac{f_h}{F_{ha}}\right)^2 \leq 1.0$$ [API Eq. 6.29]

where,

$$\mathrm{F}_{aa} = \frac{F_{xe}}{SF_x}$$

$$F_{ha} = \frac{F_{he}}{SF_h}$$

$$f_x = f_a + f_b + (0.5 f_h)$$

3 Joint Design

This chapter provides the details of the joint punching load check algorithm that is used for tubular joints in accordance with API RP 2A-WSD Section 7.3.

API RP 2A-WSD allows the joints to be designed on the basis of nominal loads in the braces.

3.1 Joint Geometry

Figure 1 illustrates some of the geometric parameters used in the punching load check.

d	Brace diameter, in
D	Chord diameter, in
g	Gap distance, in
t	Brace thickness, in
T	Chord thickness, in
θ	Angle measured from the chord to the brace

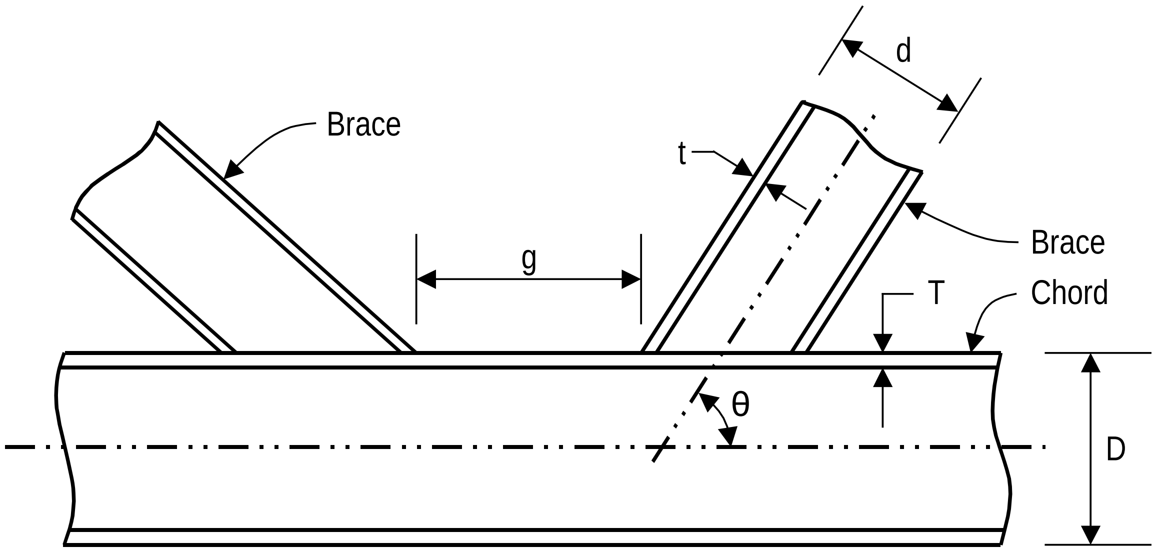

Figure 1 - Joint geometry

The following geometric parameters are derived from those in Figure 1.

$$\beta = \frac{d}{D} \quad \gamma = \frac{D}{2T} \quad \tau = \frac{t}{T}$$

3.2 Allowable Capacities

The allowable brace axial load, P_a, is defined as:

$$P_a = Q_u Q_f \frac{F_{yc} T^2}{FS \sin\theta}$$ [API Eq. 7.1]

The allowable brace bending moment, M_a, is defined as:

$$M_a = Q_u Q_f \frac{F_{yc} T^2 d}{FS \sin\theta}$$ [API Eq. 7.2]

where the safety factor, FS = 1.60.

The chord load factor, Q_f, is defined as:

$$Q_f = \left[1 + C_1\left(\frac{FSP_c}{P_y}\right) - C_2\left(\frac{FSM_{ipb}}{M_p}\right) - C_3 A^2\right]$$ [API Eq. 7.3]

The parameter, A, is defined as:

$$A = \left[\left(\frac{FSP_c}{P_y} \right)^2 + \left(\frac{FSM_c}{M_p} \right)^2 \right]^{0.5} \qquad \text{[API Eq. 7.4]}$$

where the safety factor, FS = 1.20 where the 1/3 increase is applicable. P_c is the nominal axial load and M_c is the nominal bending resultant in the chord.

$$M_c = \sqrt{M_{ipb}^2 + M_{opb}^2} \qquad \text{[API 4.3.4]}$$

The coefficients, C_1, C_2, and C_3, are determined based on API Table 7.3.

Table 2 – Coefficients, C_1, C_2, and C_3

Joint Type	C1	C2	C3
K axial	0.2	0.2	0.3
T&Y axial	0.3	0	0.8
X axial $\beta \leq 0.9$	0.2	0	0.5
X axial $\beta = 1.0$	-0.2	0	0.2
All joints moment	0.2	0	0.4

The ultimate strength factor, Q_u, is determined based on API Table 7.2.

Table 3 – Factor, Q_u

<table>
<tr><th></th><th colspan="4">Brace Action</th></tr>
<tr><th>Joint Class</th><th>Axial Tension</th><th>Axial Compression</th><th>In-plane Bending</th><th>Out-of-plane Bending</th></tr>
<tr><td>K</td><td colspan="2">$(16 + 1.2\gamma)\beta^{1.2}Q_g \leq 40\beta^{1.2}Q_g$</td><td rowspan="3">$(5 + 0.7\gamma)\beta^{1.2}$</td><td rowspan="3">$2.5+(4.5 + 0.2\gamma)\beta^{2.6}$</td></tr>
<tr><td>T&Y</td><td>30β</td><td>$2.8 + (20 + 0.8\gamma)\beta^{1.6} \leq 2.8 + 36\beta^{1.6}$</td></tr>
<tr><td>X</td><td>23β for $\beta \leq 0.9$
$20.7 + (\beta - 0.9)(17\gamma - 220)$ for $\beta > 0.9$</td><td>$[2.8 + (12 + 0.1\gamma)\beta]Q_\beta$</td></tr>
</table>

The geometric factor, Q_β, is defined as:

$$Q_\beta = \begin{cases} \dfrac{0.3}{\beta(1 - 0.833\beta)} & \text{for} \quad \beta > 0.6 \\ 1.0 & \text{for} \quad \beta \leq 0.6 \end{cases} \qquad \text{[API Table 7.2]}$$

The gap factor, Q_g, is defined as:

$$Q_g = \begin{cases} 1 + 0.2[1 - 2.8\, g/D]^3 \geq 1.0 & \text{for} \quad g/D \geq 0.05 \\ 0.13 + 0.65\phi\gamma^{0.5} & \text{for} \quad g/D < -0.05 \end{cases} \qquad \text{[API Table 7.2]}$$

$$\phi = t\,F_{yb}/(TF_y)$$

3.3 Axial and Bending Check

Joints are checked for the following condition:

$$\left|\frac{P}{P_a}\right| + \left(\frac{M}{M_a}\right)^2_{ipb} + \left|\frac{M}{M_a}\right|_{opb} \leq 1.0 \qquad \text{[API Eq. 7.6]}$$

The subscripts IPB and OPB correspond to in-plane bending and out-of-plane bending, respectively.

4 References

American Institute of Steel Construction. (1989). *Manual of Steel Construction - Allowable Stress Design* (9th ed.). Chicago, Illinois, USA: American Institute of Steel Construction.

American Petroleum Institute. (2014). *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design* (22nd ed.). Washington, District of Columbia, USA: API Publishing Services.